

# Combustion Analysis & Fuel Efficiency



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# Combustion Analysis and Fuel Efficiency

Erik Rasmussen

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## Forward

“Combustion Analysis and Fuel Efficiency” is written with emphasis on practical application. It contains the knowledge service technicians need to be productive and effective when installing and servicing combustion appliances.

This book is written at a level that most service technicians will understand. Considerable thought and study has been devoted to the organization of this book which makes it easy to follow and teach from.

Overall, I think the book is an excellent technical reference, practical learning tool, and field guide.

John Tomczyk  
Professor/Author  
Ferris State University

## Combustion Analysis

The world has entered the 21st Century and the push to reduce energy consumption and greenhouse gas emissions is stronger than ever. With dwindling resources and an ever increasing demand for power, it is time to start taking the simple measures to reduce the energy consumed by the fuel burning, emissions releasing appliances we work on every day. In this Manual we will address carbon dioxide formation and release, carbon monoxide generation, thermal heat transfer and flame temperature. Also covered are steps and procedures to increase efficiency and reduce emissions.

Readers should expect to increase their knowledge of combustion, the combustion process and combustion control. Topics such as the dynamics of carbon dioxide production, the release of heat and the oxygen relationship, and other topics will be the living breathing combustion appliance and how to ensure that your equipment is not suffocating. This combustion analysis manual is intended to raise the awareness about all things combustion and what all technicians in the HVACR trade should know. Other topics covered will range from draft and venting of fuel fired appliances to heat transfer and what effects combustion has on efficiency.

Combustion (FIRE) since the beginning of time has sometimes been a mystical thing, that all humankind has struggled to understand, conquer and control. The secrets to the realization that combustion is not that magical nor mystical are contained within the pages of this manual. Read on and become your own master of FIRE.

Erik Rasmussen

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Carrier  
Delavan, Inc  
Educational Standards Corp  
ESCO Institute  
Field Controls  
Fieldpiece Instruments  
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Green Mechanical Council  
Goodman Manufacturing  
Hago Manufacturing  
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## Chapter 1

# The Fuels of Combustion

Combustion is the rapid oxidation of any material classified as combustible matter. Natural gas (NG), fuel oil, and propane (LPG or Liquefied Petroleum Gas) are all hydrocarbon fuels (HC).

Combustion is a means to liberate stored energy from a fuel source. Fuels can be solids, liquids or gases.

For combustion to occur with a solid or liquid, both must reach a gaseous state, and combine with a enough air to reach an explosive level. To achieve this change of state, heat or an ignition source must be applied in a sufficient quantity as to gasify the fuel. There must also be enough energy present to ignite the combustible gas (Rapid oxidation).

Striking a wooden match on an abrasive surface is an example of a solid fuel changing state and releasing heat. The intense heat of the igniter (figure 1-1) causes the molecules in the match to move in rapid succession entering into a change of state. Hydrocarbons are released combining with air and ignited as a combustible mixture.

Fuels that are already in gaseous form ignite and burn easily, providing that there is sufficient oxygen available and the fuel supply is uninterrupted.

Combustion requires proportional amounts of fuel and air to be combined to reach an explosive condition. This is an air/fuel ratio.

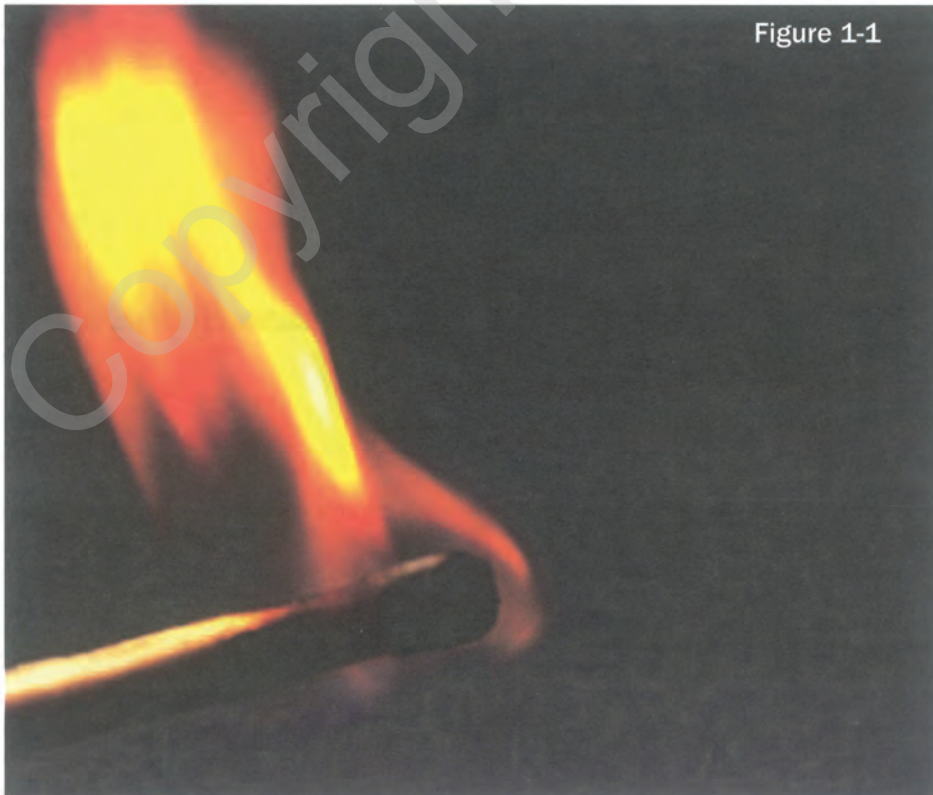


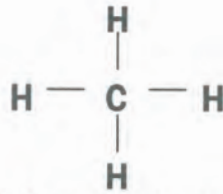
Figure 1-1



## Fuel

### Natural gas.

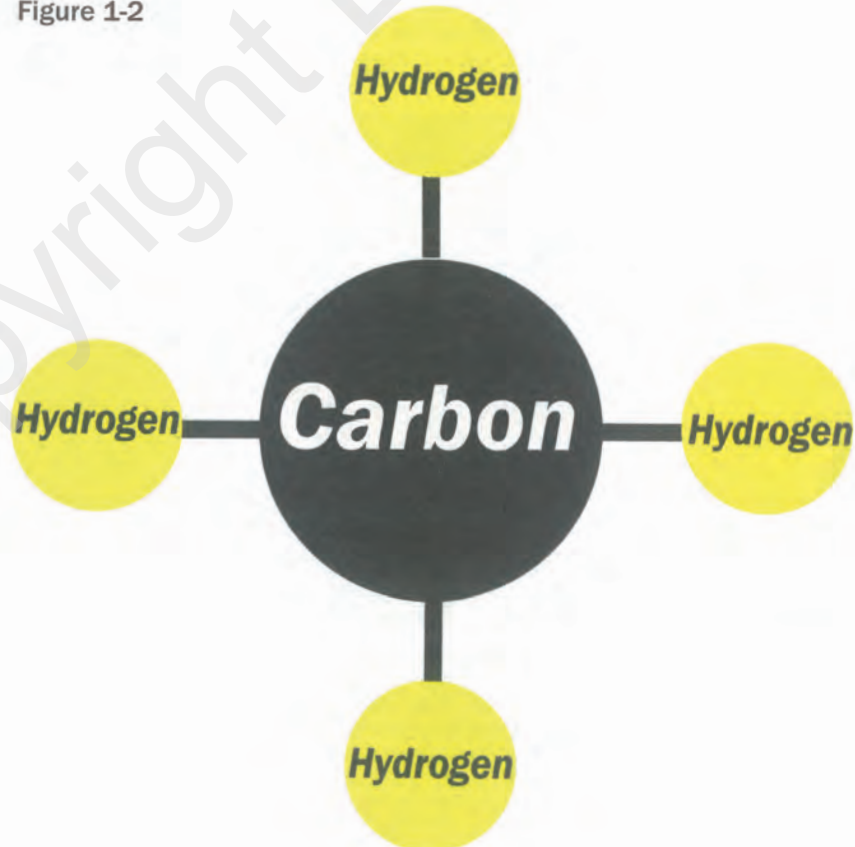
What is it and where does it come from?



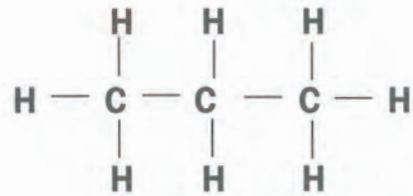
Natural gas is a fossil fuel. It comes from the ground and is the product of decayed organic matter that has been under a vast amount of pressure for an extended period of time. Natural gas contains a myriad of gases and trace elements such as methane, propane, ethane and butane to name a few. The refining process separates these gases into individual fuels for use in residential, commercial and industrial applications. Natural gas distributed for consumer use is comprised of approximately 95% methane. Methane is the purest form of natural gas and contains approximately 1,000 BTUs per cubic foot. Natural gas is lighter than air and has a .60 specific gravity, and is a clean burning fuel providing that combustion is complete.

The chemical formula of methane is CH<sub>4</sub>. Each methane molecule consists of one carbon molecule and four hydrogen molecules (figure 1-2).

Figure 1-2



## Liquefied Petroleum Gas (LPG) Propane



When natural gas is extracted from the well it is referred to as sour gas and contains corrosive compounds such as sulfur. These corrosive compounds must be removed. The removal process is called sweetening. When the gas has been sweetened it contains various amounts of hydrocarbons. When hydrocarbons are refined they separate into wet and dry gases. Natural gas is a dry gas. The wet gas is separated into propane and other gases such as butane.

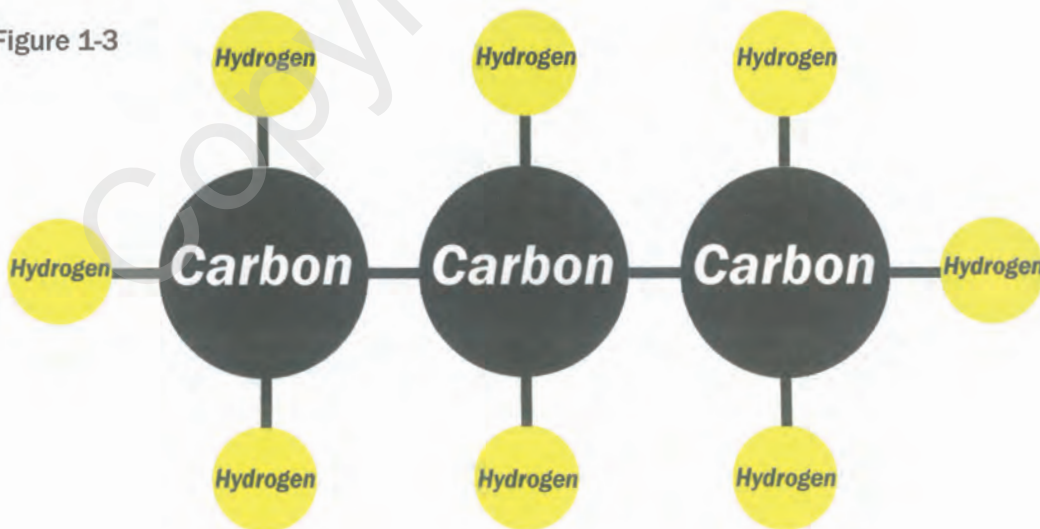
Propane has some advantages as a fuel, it stores easily in tanks as a liquid under pressure. Has a high energy content of 2520 BTUs per cubic foot of vapor, and burns clean providing combustion is complete.

The ease in transporting propane makes it a viable fuel source for rural communities in the absence of natural gas.

Propane uses for internal combustion engines are numerous, including cars, buses, forklifts and floor buffers. Propane is also used as a heating fuel.

The chemical formula for propane is  $\text{C}_3\text{H}_8$ . Each molecule has three carbon and eight hydrogen atoms (figure 1-3). Propane is heavier than air having a 1.52 specific gravity.

Figure 1-3

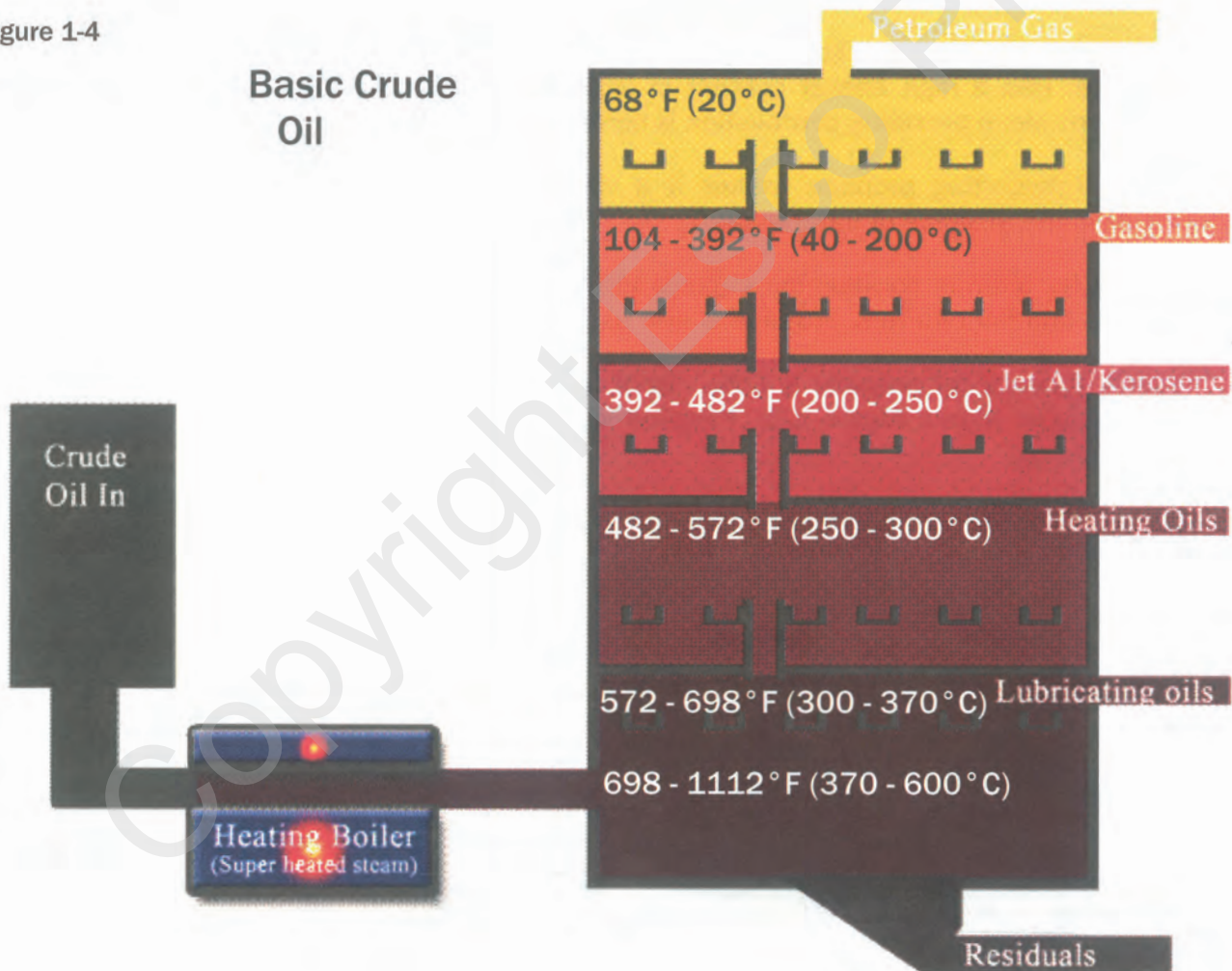


**Fuel Oil**

Fuel oil is produced through the distillation of crude oil. Many fuels are produced through the distillation and fractioning process at the refinery. The basic distillation process is shown in the diagram below. It is very easy to separate the different grades of fuel because all fuels have different boiling points. Fuels with higher boiling temperatures have a higher carbon concentration per molecule. Petroleum gas molecules range in structure from 1 to 4 carbon atoms per molecule and the heavy oils and residuals may range up to 80 carbon atoms per molecule.

The increased demand for gasoline, diesel fuels and the lighter grades of fuel has prompted the use of a process called cracking. This process is where the hydrocarbon chains are broken down into smaller chains and are blended to produce more of the desired fuels.

Figure 1-4



The steps of fractional distillation are as follows:

1. The mixture of two or more substances (liquids) is heated with different boiling points to a high temperature. Heating is usually done with high pressure steam to temperatures of about 1,112 degrees Fahrenheit / 600 degrees Celsius.
2. The mixture boils, forming vapor (gases); most substances go into the vapor phase.
3. The vapor enters the bottom of a long column (fractional distillation column figure 1-4 ) that is filled with trays or plates.
  - a) The trays have many holes or bubble caps (like a loosened cap on a soda bottle) in them to allow the vapor to pass through.
  - b) The trays increase the contact time between the vapor and the liquids in the column.
  - c) The trays help to collect liquids that form at various heights in the column.
  - d) There is a temperature difference across the column (hot at the bottom, cool at the top).
4. The vapor rises in the column.
5. As the vapor rises through the trays in the column, it cools.
6. When a substance in the vapor reaches a height where the temperature of the column is equal to that substance's boiling point, it will condense to form a liquid. (The substance with the lowest boiling point will condense at the highest point in the column; substances with higher boiling points will condense lower in the column.)
7. The trays collect the various liquid fractions.
8. The collected liquid fractions may:
  - a) pass to condensers which cool them further, and then go to storage tanks
  - b) go to other areas for further chemical processing

Freudenrich, Craig C., Ph.D. "How Oil Refining Works: Fractional Distillation." HowStuffWorks. 2007. 15 Jan 2007 <<http://science.howstuffworks.com/oil->



refining4.htm>.

### **Fuel Oil Properties**

Liquid fuel characteristics must be understood to effectively service this type of appliance.

**Flash point** is when a liquid fuel is heated and the vapors begin to form above the surface of the liquid fuel. Flash point is described as the lowest temperature at which sufficient quantity of vapor will ignite when exposed to a source of ignition. The flame is extinguished when the vapor burns faster than it is being produced by the heated fuel. The fuel industry requires that liquid fuels meet a set standard of minimum flash point. Flash point is specific for each grade of fuel. Examples: kerosene has a minimum flash point of 100°F (38°C), as opposed to number 6 oil that has a minimum flash point of 140°F (60°C).

**Fire Point** is defined as the lowest temperature at which a heated liquid fuel produces a sufficient quantity of combustible vapor to burn continuously. There is no set standard for the minimum fire point of liquid fuels, although it may give a very clear indication of a fuel's ability to burn.

**Cloud Point** is the temperature at which wax crystals begin to form. Wax in the fuel is comprised of paraffinic hydrocarbons and works as a lubricant. Unfortunately, the wax congeals at a higher temperature before the other hydrocarbon compounds causing filter clogging problems.

**Pour Point** is the temperature at which oil will barely flow. This is usually 5°F above the point where oil forms a solid mass. The ASTM D396 Standard for fuel oils lists 20°F as the maximum pour point for #2 fuel oils. However random analyses show that the typical pour point is -20°F. To avoid problems in certain cold applications, #2 fuel oil is sometimes blended with approximately 25% #1 fuel oil to lower the pour and cloud points. (Pour point definition from Beckett's Professional service mans guide to oil heat)

**Viscosity** is the term used to describe a fluids internal resistance to flow. A thick heavy fluid has a high viscosity where as a thinner lighter fluid would have a low viscosity (figure 1-5). The higher the viscosity the greater the resistance to flow. Viscosity is easily affected by temperature. When a fluid is exposed to cold temperatures it becomes more viscous and has a higher resistance to flow. The standard temperature for testing fuel is 100°F (38°C).

Fuel volume is also affected by temperature and it is necessary to compensate deliveries of fuel or metered fuel purchases such as fuel oil and gasoline to 60°F (15.6°C). The following graphic (figure 1-6) shows an approximate change in volume based on temperature and has been exaggerated for graphic purposes.

\*Note: As the volume of fuel increases, the weight remains constant.